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Determination of $\phi_1^{\rm eff}(\beta_{\rm eff})$ by $B^0 \to K^+K^-K^0_S$, $\pi^+\pi^-K^0_S$ and $K^0_SK^0_SK^0_S$ decays

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Measurements of the CP violation parameter $\phi_1^{\rm eff}(\beta_{\rm eff})$ by $b \to s$ penguin mediated three-body B decays, $B^0 \to K^+K^-K^0_S$, $\pi^+\pi^-K^0_S$ and $K^0_SK^0_SK^0_S$ are reviewed in this report.

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1 Introduction

Time-dependent CP violation measurements started with tree-mediated B decays such as $B^0 \to J/\psi K^0$ in order to perform critical tests of Kobayashi-Maskawa theory. The most promising measurement is the CP violation caused by interference between mixing and decay. If we choose the B meson decay mode caused by the amplitude containing no complex phase, CP violation arises from the $B^0 - \overline{B}^0$ mixing that contains one of the Kobayashi-Maskawa matrix element V_{td} and thus is directly related to the CP violation angle $\phi_1(\beta)$ *.

Penguin-mediated B decays are sensitive to New Physics, which can provide observed CP-violating parameters different from those obtained in tree-mediated processes. In the Standard Model (SM), the $b \to s$ transition does not contain a complex phase in the decay amplitude and thus is expected to exhibit the same time-dependent CP violation as $B^0 \to J/\psi K^0$. In other words, the New Physics effect contribute to the decay amplitude because of its one-loop nature and could appear as possible deviations of CP violation parameters from the SM expectation. The first round of measurements used a quasi-two-body approach, i.e. $B^0 \to \phi K^0$, $\rho^0 K^0_S$, and so on. However, several contributions are overlapping because of relatively wide natural widths of the involved resonances. For example, in $B^0 \to K^+K^-K^0_S$ case, ϕ, f_0 and other resonant or non-resonant contributions are there, and they interfere with each other. Therefore, in order to resolve those interfering contributions into three-body final state such as $K^+K^-K^0_S$ or $\pi^+\pi^-K^0_S$, the time-dependent Dalitz distribution is fitted to extract CP violation parameters. By this technique, we can measure $\phi_1^{\rm eff}$ and $\mathcal{A}_{CP}$ which denote mixing-induced and direct CP asymmetries, respectively.

In addition to these, the $B^0 \to K^0_S K^0_S K^0_S$ mode is also discussed. Due to Bose statistics, this final state is purely CP-even. The BaBar collaboration has made an attempt to resolve intermediate states using Dalitz distribution.

2 Time-dependent $B^0 \to K^+K^-K^0_S$ Dalitz analysis

The time-dependent Dalitz analysis for $B^0 \to K^+K^-K^0_S$ has been performed by both the BaBar [1] and Belle [2] Collaborations. Here, ϕK^0_S, $f_0 K^0_S$, $f_X(1500)K^0_S$, $\chi_{c0}K^0_S$ and non-resonant contributions are taken into account in the fit to the time-dependent Dalitz distribution. With the currently available statistics, we find multiple solutions. In the Belle measurement, there are four solutions. The preferred solution can not be selected by the fit likelihood alone. With external information related to $f_0(980)$ and f_X branching fractions into charged pion and Kaon pairs, one of them is preferred, where f_X is assumed as $f_0(1500)$. In the BaBar measurement, the selected candidate events are categorized into two groups, low and high K^+K^- mass regions. The

*ϕ_1 is used hereafter.

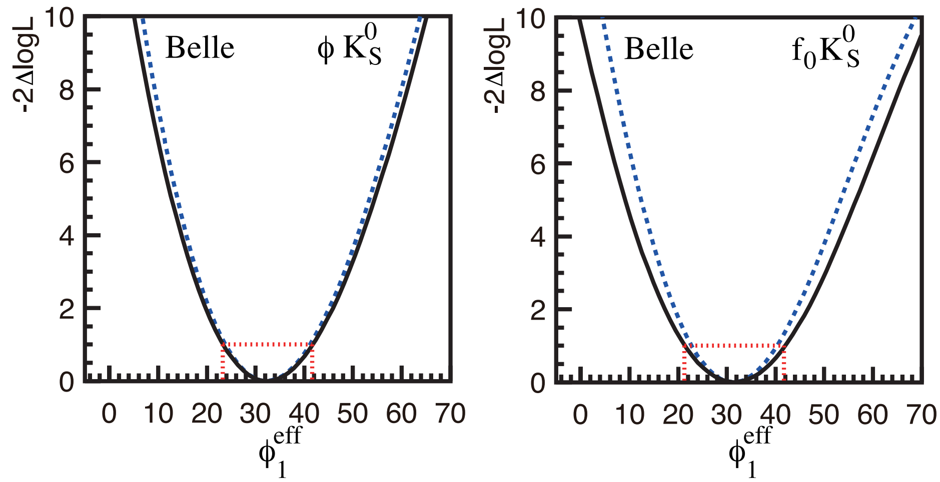

Figure 1: Likelihood scans of $\phi_1^{\rm eff}$ (in degree) of $B^0 \to \phi K^0_S$ (left) and $B^0 \to f_0 K^0_S$ (right) for the preferred solution in the time-dependent Dalitz analysis for $B^0 \to K^+K^-K^0_S$ decays at Belle. The solid (dashed) curve contains the total (statistical) error and the dotted box indicates the parameter range corresponding to $\pm 1\sigma$.

most important process, ϕK^0_S is contained in the low K^+K^- mass region, and two solutions are found in the low mass region fit. Since those two solutions exhibited $\Delta \log(\mathcal{L}) = 0.1$, the solution (1) in Ref. [1] is presented as the preferred solution.

With higher statistics the maximum of the likelihood itself will determine the most preferred solution clearly. The preferred solution results of each experiment are summarized in Figs. 3 and 4 for $B^0 \to \phi K^0_S$ and $B^0 \to f_0 K^0_S$, respectively. So far, we have not observed significant deviation from the measurements with $B^0 \to (c\bar{c})K^0$.

3 Time-dependent $B^0 \to \pi^+\pi^- K^0_S$ Dalitz analysis

In the $B^0 \to \pi^+\pi^- K^0_S$ decay, $\rho^0 K^0_S$ and $f_0(980)K^0_S$ are the main contributions. Since ρ^0, f_0 and other possible intermediate states have wide natural widths, they are overlapping in $\pi^+\pi^-$ invariant mass distribution. Therefore a time-dependent Dalitz analysis is very effective to extract CP violation parameters while resolving interference among possible contributions. The BaBar and Belle Collaborations have both performed this measurement [3] [4]. Similarly as the $B^0 \to K^+K^-K^0_S$ case, multiple solutions are found. BaBar and Belle found two and four solutions, respectively. The solution presented as nominal is selected by an ensemble test as well as external information at Belle, while likelihood scan results are used to specify the most preferred solution at BaBar. The results of the preferred solution of each experiment are summarized in Figs. 5 and 6 for $B^0 \to \rho^0 K^0_S$ and $B^0 \to f_0 K^0_S$, respectively. So far, no

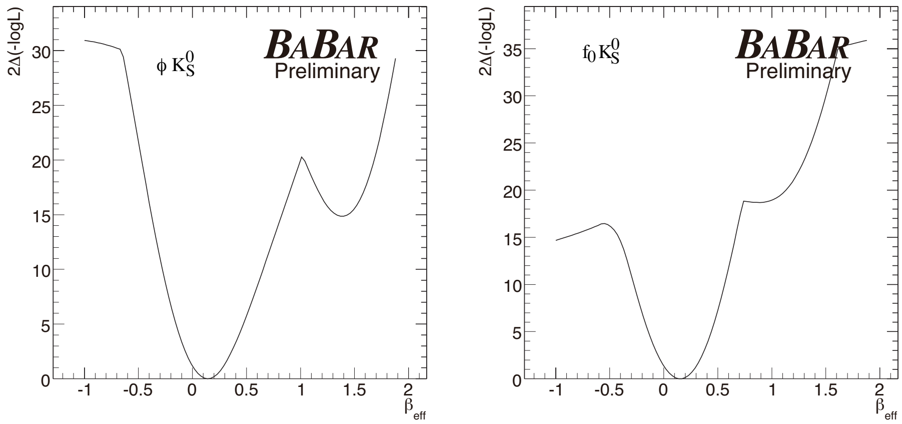

Figure 2: Likelihood scans of $\phi_1^{\rm eff} = \beta_{\rm eff}$ (in radian) of $B^0 \to \phi K^0_S$ (left) and $B^0 \to f_0 K^0_S$ (right) for the preferred solution of low mass fit for $B^0 \to K^+K^-K^0_S$ decays at BaBar.

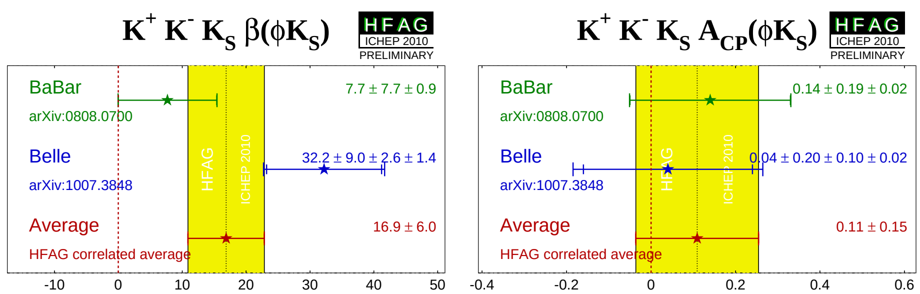

Figure 3: The preferred solution's CP violation parameters for $B^0 \to \phi K^0_S$.

significant deviation from the measurements with $B^0 \to (c\bar{c})K^0$ has been observed.

4 $B^0 \to K^0_S K^0_S K^0_S$ mode

This is a purely CP-even final state though there can be several intermediate states [5]. Since there are no up type quarks in the decay amplitude, it has very small Cabibbo-suppressed tree contribution and is thus theoretically clean. Because of this fact, time-dependent CP violation measurements have been performed on the inclusive three-body final state. The BaBar result [6] is

$$\sin 2\phi_1^{\rm eff} = 0.90^{+0.18}_{-0.20}({\rm stat.})^{+0.03}_{-0.04}({\rm syst.}) \quad (1)$$

$$\mathcal{A} = -\mathcal{C} = +0.16 \pm 0.17({\rm stat.}) \pm 0.03({\rm syst.}), \quad (2)$$

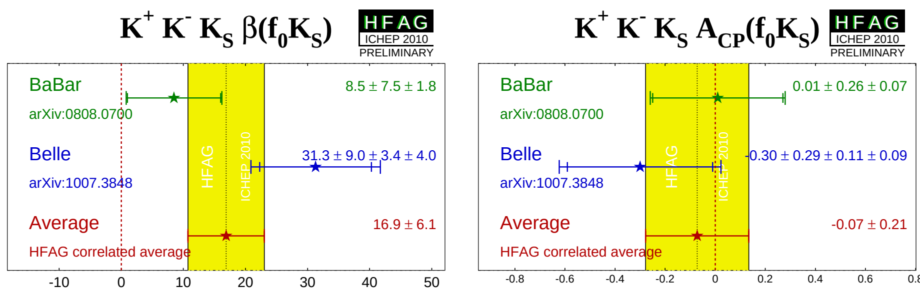

Figure 4: The preferred solution's CP violation parameters for $B^0 \to f_0 K_S^0$ in $f_0 \to K^+K^-$ mode.

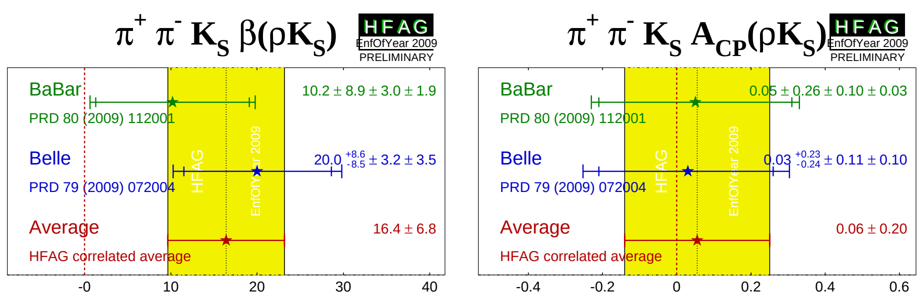

Figure 5: The preferred solution's CP violation parameters for $B^0 \to \rho^0 K_S^0$.

while the Belle measurement [7] is

$$\sin 2\phi_1^{\mathrm{eff}} = 0.30 \pm 0.32(\mathrm{stat.}) \pm 0.08(\mathrm{syst.}) \quad (3)$$

$$\mathcal{A} = -\mathcal{C} = +0.31 \pm 0.20(\mathrm{stat.}) \pm 0.07(\mathrm{syst.}). \quad (4)$$

In both experiments, precision is still limited by statistics and therefore Super B-factory statistics is necessary to probe the New Physics effect as possible deviation from the values of CP violation parameters obtained by $B^0 \to J/\psi K^0$.

Recently, an attempt to resolve intermediate states has been carried out by the BaBar collaboration, where 200±15 events are found. A baseline model consists of $f_0 K_S^0$, $\chi_{c0} K_S^0$ and non-resonant contribution. Then a resonance is added and the likelihood is scanned varying its mass and width. As a result, $f_0(1710)$ and $f_2(2010)$ are found to be significantly contributing, while there was no evidence of $f_X(1500)$ [8].

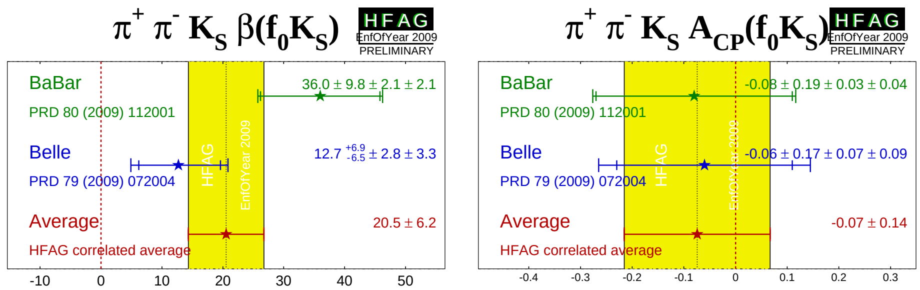

Figure 6: The preferred solution's CP violation parameters for $B^0 \to f_0 K_S^0$ in $f_0 \to \pi^+\pi^-$ mode.

5 Summary

In summary, for $B^0 \to K^+K^-K_S^0$ and $B^0 \to \pi^+\pi^-K_S^0$ decays, the time-dependent Dalitz analysis technique has been performed by both BaBar and Belle collaborations. In both experiments, multiple solutions are found and we are not always able to select one of them by the fit goodness alone. Therefore the most preferred solution is identified with likelihood scan results, an ensembel test as well as external information, depending on each analysis. The preferred solutions' CP violation parameters, $\phi_1^{\rm eff}$ and $\mathcal{A}_{\mathcal{CP}}$ do not exhibit significant deviation from the ones obtained by $B^0 \to (c\bar{c})K^0$. With Super B-factory level statistics, the best of the multiple solutions can be identified from likelihood alone. In $B^0 \to K_S^0K_S^0K_S^0$ mode, $f_0(1710)$ and $f_2(2010)$ are found to give significant contributions in addition to the known components, $f_0K_S^0$ and $\chi_{c0}K_S^0$.

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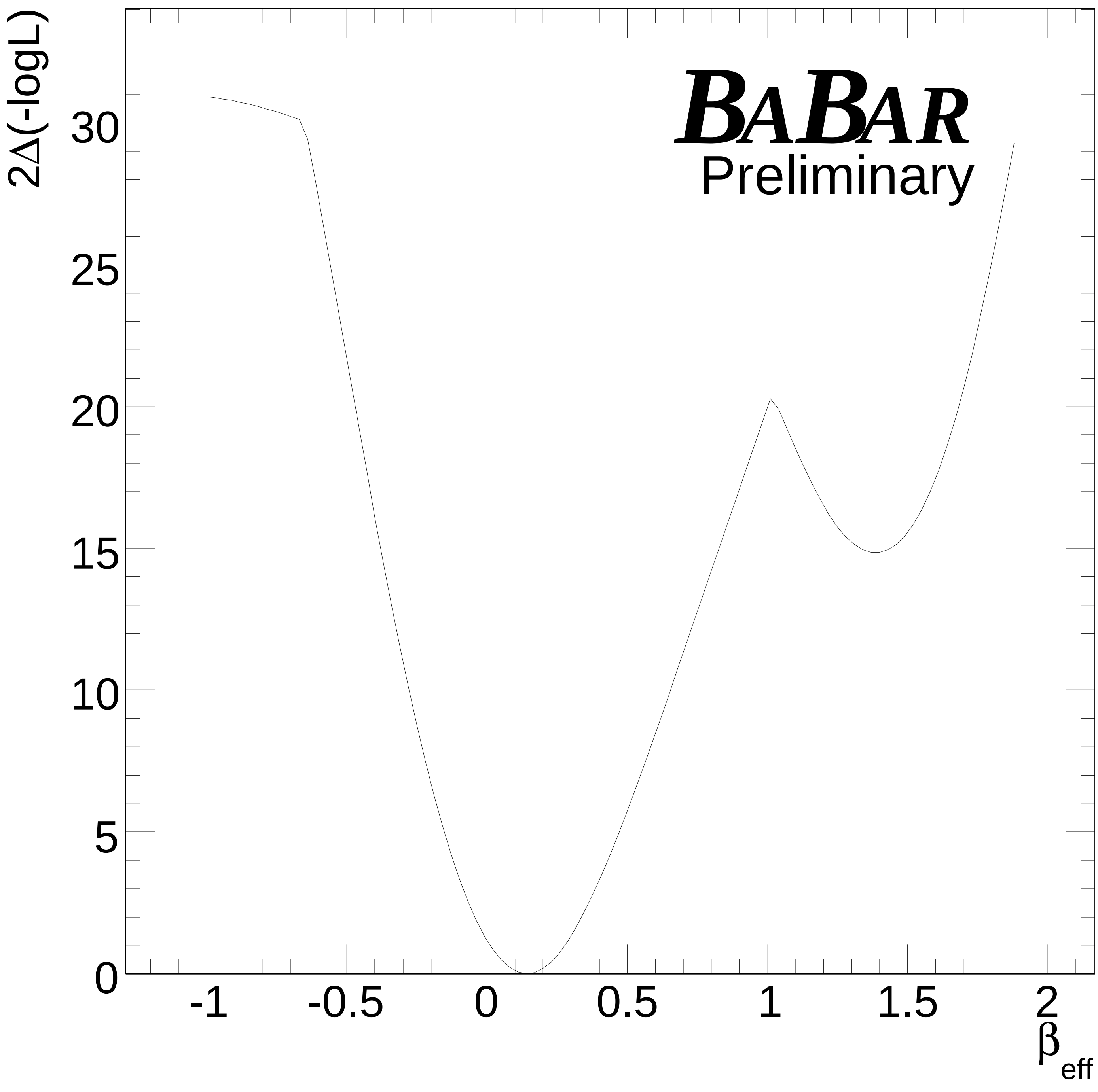
BABAR
Preliminary
2Δ(-logL)
30
25
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-1
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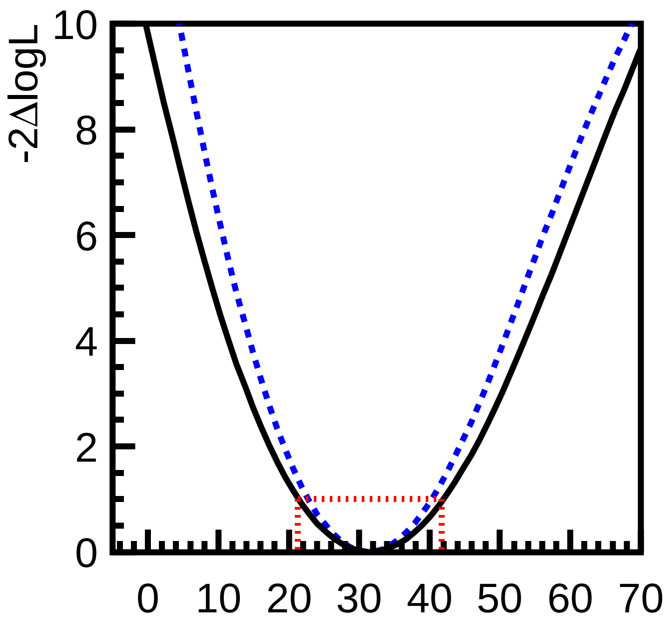
1.5
2
β eff



-2ΔlogL
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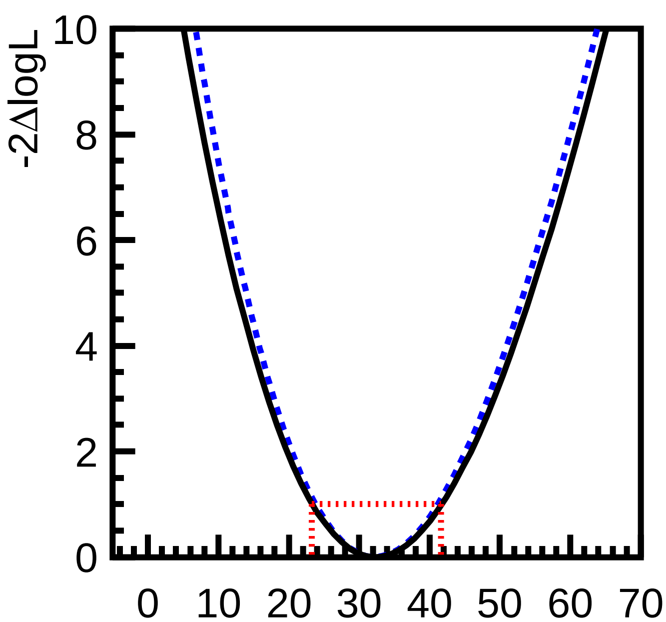

-2ΔlogL
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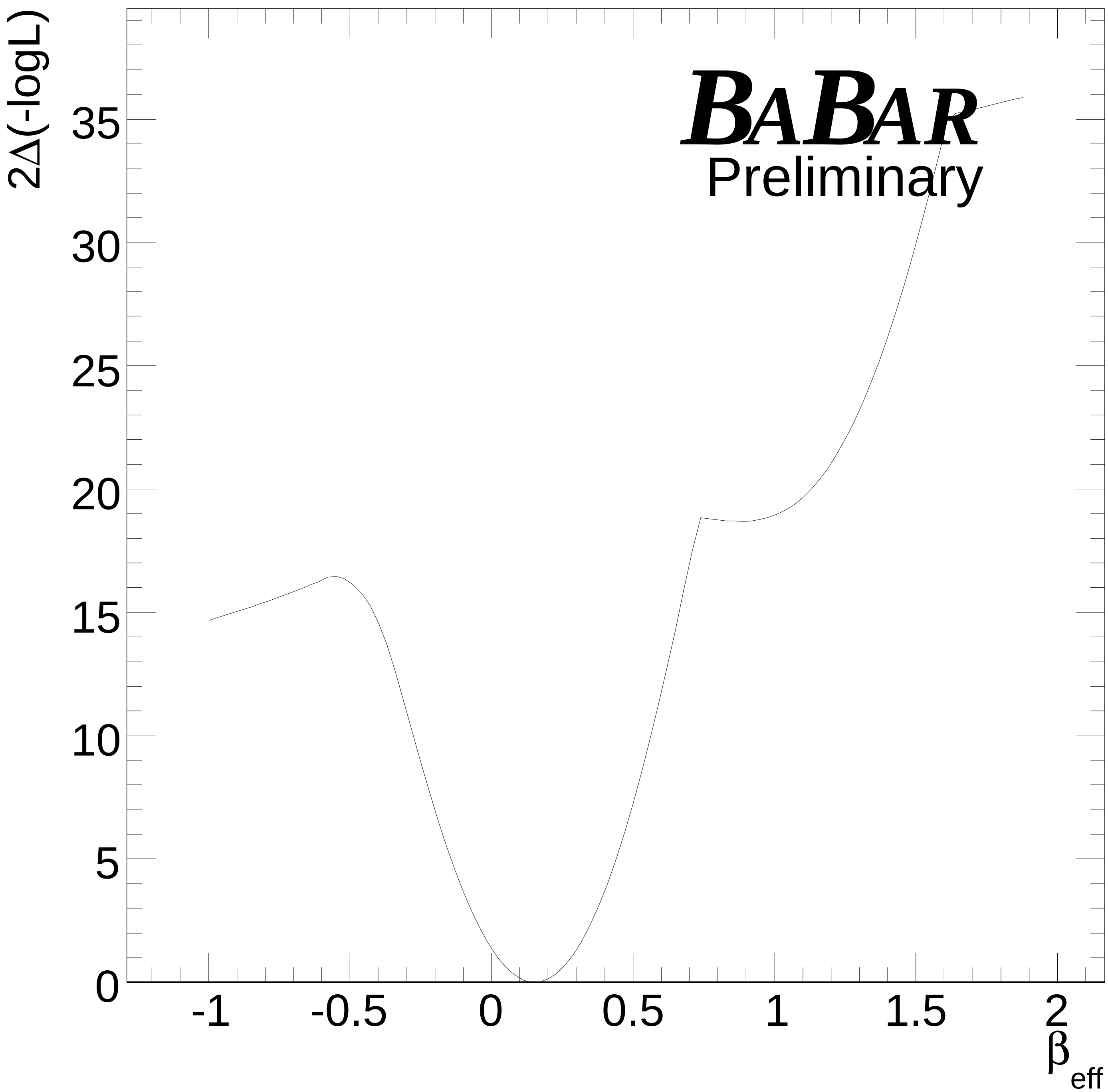

BABAR
Preliminary
2Δ(-logL)
0
5
10
15
20
25
30
35
-1
-0.5
0
0.5
1
1.5
2
β_{eff}